

Synthesizing Sounds from Physically Based Motion

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Introduction

- **Goals**
 - Generate audio from physical simulation
 - General purpose method
 - Same simulation as used for visuals
 - Low additional overhead
- Same motivation as for physically based animation



Related Work

- **Work in Graphics Community**
 - Graphics and Sound
Hahn et al. 95, Takala & Hahn 92
 - Sound Propagation
Furukhouser et al. 99 & 98, Min & Furukhouser 00, Morikis et al. 00, Tsingos et al. 01
 - Simulated Sound
Terzopoulos & Fleisher 88, van den Doel & Pai 98, van den Doel et al. 01
- Other work in Digital Sound/Music
(please see paper)



Overview



Simulation Requirements

- Temporal Resolution
- Dynamic Deformation Modeling
- Boundary Representation
- Physical Realism



Simulation Method

- Tetrahedral Finite Elements
 - Linear basis functions
 - Green's Strain
(non-linear, finite deformation)
 - Rayleigh Damping
 - Explicit time integration
- Details in O'Brien & Hodgins (SIGGRAPH 99)



Surface Vibrations

- Relate surface movement to pressure

$$p = z v \cdot \hat{n}$$

$$z = \rho c = 415 \text{ Pa} \cdot \text{s/m}$$

Specific acoustic impedance

- Approximate p as const. over triangles



Surface Vibrations

- For each triangle, band-pass filter to remove info outside audible range
 - Low-pass with windowed sinc function
 - High-pass with DC-Blocking filter
- Result: pressure as piece-wise const function over the surface(s)

SIGGRAPH 2001

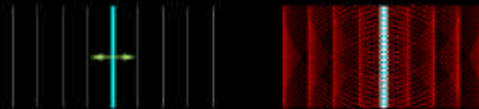
Radiation and Propagation

- Ignore reflection and diffraction
- Account for visibility
- Account for distance falloff

SIGGRAPH 2001

Radiation and Propagation

- Model wavefront as sum of simple waves from each triangle (Huygen's principle)



- Simple wave for each triangle face (vibrating piston)

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Radiation and Propagation

$$s = \frac{\bar{p} a \delta_{x \rightarrow r}}{||\bar{x} - r||} \cos(\theta)$$

Labels for the equation components:

- Signal at receiver (points to s)
- Filtered pressure over triangle (points to \bar{p})
- Area of triangle (points to a)
- Visibility term (points to $\delta_{x \rightarrow r}$)
- Approximation of beam pattern (points to $\cos(\theta)$)
- Distance falloff (points to $||\bar{x} - r||$)

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Radiation and Propagation

- Account for travel time $d = \frac{||\bar{x} - r||}{c}$



- "Splat" into accumulation buffer

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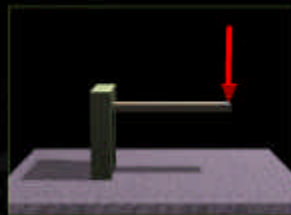
Results

- Stereo from two listener locations
- Omni-directional receivers
- Located at rendering viewpoint
- 20 cm separation perpendicular to viewing and up directions
- 44.1 K Hz audio rate
- Simulation time-step between 10^{-5} and 10^{-7} seconds

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mpg video

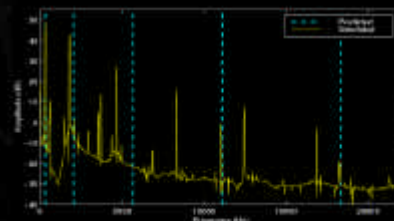
Plucked Bar



- Fixed at one end
- Impulse applied at the other

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Plucked Bar



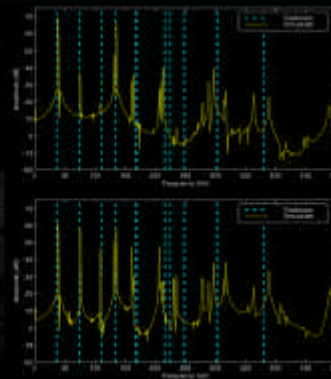
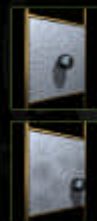
Square Plates



- Fixed along edges
- Struck by mass at different locations

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Square Plates



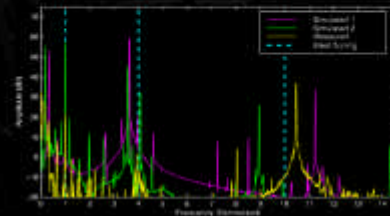
Vibraphone Bar



- Spring mounted at nodes of first mode
- Compared to real bar and ideal tuning

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Vibraphone Bar



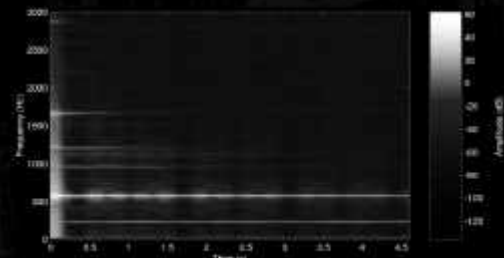
Swinging Bar



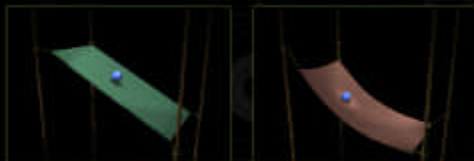
- Doppler effects

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Swinging Bar



Slab and Ball



- Both objects sounding
- Mounted on springs

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Stiff Sheet



- Non-linear deformation

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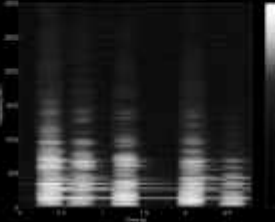
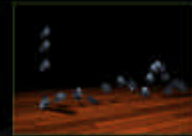
Bowls



- Only bowl is sounding
- Bounces excite different modes

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Bowls



Future Work

- Other types of simulations
 - Rigid bodies or fluids
 - Large timestep implicit integrators
- Hybrid methods
 - Visual = 60, Tactile = 1500, Audio = 40000
- Better propagation and listener models
- Calibration
- Useful as a debugging tool?

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VIRTUAL INTERACTION
AND SOUND IMAGES

